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ORIGINAL ARTICLE

Content of macronutrients in needles and litterfall in Norway spruce stands of different age in the Potok Dupniański catchment, the Silesian Beskid

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Abstract

The nutrient content of needles and litterfall in different age classes of planted Norway spruce [*Picea abies* (L.) Karst] was determined in the Potok Dupniański catchment, the Silesian Beskid in 1999–2003. The results were put in relation to age, vitality and health of the stands. The methods were according to the guidelines of the ICP – Forest Manual. In each spruce stand (1st, 2nd, 5th and 6th age class) needles were taken during August 1999 and 2003, and litterfall was sampled during five years. Material from litterfall traps was dried and sorted into: needles, cones, seeds, shoots and "others". The content of C, N, S, K, Ca and Mg was determined in both needles and litterfall fractions.

Concentrations of K, Mg and Ca in needles were below optimum level. The ratios between sulphur and nitrogen with respect to cations increased after 5 years, which indicated losses of basic cations from the spruce stands, and especially in the oldest spruce stands. This may change the vitality and health of spruce. Litterfall did not seem to cover the needs of K, Mg and Ca for proper development of Norway spruce stands. In order to improve their stability we have to increase the retention and availability of basic cations.

Keywords

Picea abies, litterfall, macroelements, needles, Silesian Beskid

Introduction

In the south – western part of the Carpathians, and especially in the Silesian Beskid several investigations have shown a considerable decrease in soil pH during recent decades, and the acid rain seems to be the most significant contributory factor. The Silesian Beskid is heavily polluted from various sources, but especially from Karvina and Ostrava regions in the Czech Republic as well as Rybnik and Katowice regions on the Polish side (Staszewski et al. 1999; Bytnerowicz et al. 1999, 2002; Maňkovská et al. 2002; Małek et al. 2005; Kulhavý et al. 2005; Florek et al. 2007). Both sulphur and nitrogen (as NO_3^- and NH_4^+) contribute to soil acidification, but whereas deposition of S is decreasing, N deposition seems to be constant or increasing slightly (Małek et al. 2005, Małek and Astel 2008). There has been therefore growing concern about the role of N in forest dieback (van Breemen and van Dijk 1987; Aber 1992; Hornung and Sutton 1995, Folwer et al. 2007; Małek and Astel 2008; Sicard et al. 2007; Małek 2010).

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Due to the anthropogenic pressure on forests in the Silesian Beskid and especially concerning the Istebna spruce provenances in the Potok Dupniański catchment, earlier studies focused on the balance of incoming and outgoing elements of spruce stands. Up to date, special attention has been put to changes in the concentration of anions and cations of rain water in open field, after passing the canopy as throughfall, in the top soil surface water, and in superficial ground water (lysimeters were placed at the depth of 20 cm to pick up water by horizontally and vertically flows). Studies have also focused on determining the chemistry and productivity of forest soils formed from the Istebna sandstone, on the nutrient status of trees and on amounts of litterfall at different developmental stages of spruce stands (1st, 2nd, 5th and 6th age class) during the year 1999 (Małek 2002). The aim of the present study was to examine the nutrient content in needles and litterfall of different age classes of the planted Norway spruce stands in the Potok Dupniański catchment, the Silesian Beskid, Southern Poland, during 1999–2003, with relation to the age, vitality and health of the stands.

Material and methods

The Potok Dupniański Catchment of 1.68 km^2 area is located in southern Poland in the Silesian Beskid Mts. (49°34'N, 18°50'E), not far from the main industrial centres. The catchment is covered with the Istebna provenances of Norway spruce [*Picea abies* (L.) Karst.] stands of different age growing on dystric cambisols developed on the bedrock of Istebna sandstone. Equipment for measuring litterfall in pure spruce stands (one monitoring plot in each age class) was set up in 1998. According to the Polish procedures (Zasady Hodowli Lasu 2003) from 1st to 6th age-class stands are discerned, but only the 1st, 2nd, 5th and 6th age classes were found in this catchment at the same elevation. In 1999, they were 11, 24, 91, and 116 years old, respectively. Descriptive characteristics of the spruce stands is presented in Tab. 1.

The studies were conducted during 1999–2003 following the methods described in the ICP-Forest Manual (1998). In August 1999 and 2003, on each study plot defoliation and discoloration were studied. Defoliation and discoloration were estimated on 30 permanently marked trees from predominant and dominant trees (canopy classes 1 and 2 according to the system of Kraft) following the ICP Forest Manual (1998). Needles were collected in August 1999 and 2003 from the seventh verticil, counting from the tree top, and from three individuals four samples were taken from each direction (north, east, west, south) of the dominant tree in each stand age class.

In autumn 1998, nine collectors for litterfall with the diameter of inlets equalling 0.170 m^2 were installed at steady intervals at the height of 130 cm above the soil level in each study plot. The sampling of litterfall was performed on the first day of each month from 1st May to 30th April next year.

Tab. 1. Descriptive characteristics of *Picea abies* stands with litterfall plots in the Potok Dupniański Catchment. Significant differences between 2003 and 1999 at p = 0.05 are indicated by * standard errors given in parentheses

Kind of plot	Age [year]	Elevation m a.s.l.	Diameter [cm]	Height [m]	Number of trees [no/1ha]	Defoliation [%]	Discoloration [%]
1999							
1st age class	11	720	2.2	1.5	20 150	10 (0.5)	5 (0.5)
2nd age class	24	700	11.7	12.6	2 611	30 (1.5)	15 (0.7)
5th age class	91	660	39.7	37.8	382	31 (1.6)	16 (0.7)
6th age class	116	700	42.1	36.6	414	33 (1.5)	19 (12)
2003							
1st age class	16		3.6	5	13 758	15(0.8)	10 (0.9)*
2nd age class	29		14.7	16.2	2 070	34 (1.8)	22(1.6)*
5th age class	96		42.1	39.1	350	35 (2.0)	23(1.5)*
6th age class	121		45.5	38.8	330	36 (1.9)	24 (1.7)*

The needles were sorted to current (c) and second year (c+1) needles, and litterfall was sorted to different fractions: needles, shoots, cones and "others", dried at the temperature 65°C and weighed. Total content of the elements K, Ca and Mg were determined in the plant material after wet mineralization in a HNO_3 and $HClO_4$ solution at the ratio 1:4 with the Atomic Absorption Spectrophotometer Varian AA-20, whereas the elements C, N, and S were determined with the LECO CNS 2000 analyzer.

The results were analyzed by the STATISTICA 6.0 software. For comparison of the average values of elements, defoliation and litterfall in four groups of spruce stands (1st, 2nd, 5th and 6th age classes) and between years 1999 and 2003, the Tukey's test was used with the significance level α = 0.05.

Results

The contents of elements in needles, as determined for the two youngest age classes (c and c+1), are presented in Tab. 2.

Sulphur

The content of S was at its optimum value (above 1.1% in 1999 and 2003) only in the oldest spruce stand (cf Stefan et al. 1997). Similar values were obtained from Brenna and Salmopol for a spruce stand of the 5th age class (Bytnerowicz et al. 1999; Staszewski et al. 1999).

Nitrogen

The content of N in all development stages of the spruce stand in 1999 was low and below optimal values (cf Fiedler and Katzschner 1990), with current needles: 0.92–1.02%, and c+1: 0.83–1.04% (Tab. 2). After five years, in 2003, the average content of this element significantly increased in all stand age classes with current needles: 0.98–1.46%, and c+1: 1.02–1.32%. In the oldest age class the increase was most obvious, with current needles from 0.93 to 1.46% and c+1 from 0.85 to 1.25%. Here, the averages reached normal and optimal levels, except for the 1st age class. The increase of N was significant in all spruce stands except for the youngest one.

Tab. 2. Average total content (in % of dry mass) of selected elements in *Picea abies* needles and relation of these elements according to Cape et al. (1990) - cutting in 1999 and 2003 at different age of *Picea abies* stands at the Potok Dupniański catchment. Significant differences between 2003 and 1999 at p = 0.05 are indicated by *, between the oldest and the youngest age classes by ** - standard errors are given in parentheses

Spruce age class	Needle age class	S	N	K	Ca	Mg
1999						
1st	c	0.070 (0.003)	0.920 (0.045)	0.720 (0.031)	0.400 (0.020)	0.064 (0.003)
	c+1	0.110 (0.005)	0.830 (0.041)	0.450 (0.021)	0.590 (0.028)	0.063 (0.003)
2nd	c	0.090 (0.004)	1.020 (0.051)	0.730 (0.035)	0.240 (0.012)	0.064 (0.003)
	c+1	0.120 (0.006)	1.040 (0.050)	0.560 (0.024)	0.310 (0.015)	0.059 (0.002)
5th	c	0.090 (0.003)	1.010 (0.048)	0.750 (0.036)	0.220 (0.009)	0.054 (0.002)
	c+1	0.100 (0.005)	0.830 (0.041)	0.570 (0.026)	0.380 (0.017)	0.044 (0.002)
6th	c	0.120 (0.006)	0.930 (0.045)	0.640 (0.031)	0.210** (0.009)	0.058 (0.002)
	c+1	0.120 (0.005)	0.850 (0.041)	0.560 (0.027)	0.450 (0.022)	0.055 (0.002)
2003						
1st	c	0.060 (0.002)	0.980 (0.045)	0.550* (0.026)	0.290* (0.014)	0.060 (0.003)
	c+1	0.070 (0.003)	1.020 (0.052)	0.380* (0.019)	0.450* (0.022)	0.055 (0.002)
2nd	c	0.070 (0.003)	1.310* (0.055)	0.650* (0.032)	0.230 (0.011)	0.059 (0.003)
	c+1	0.080 (0.004)	1.320* (0.056)	0.490* (0.024)	0.310 (0.015)	0.053 (0.002)
5th	c	0.080 (0.004)	1.270* (0.060)	0.540* (0.026)	0.230 (0.010)	0.051 (0.002)
	c+1	0.080 (0.004)	1.220* (0.061)	0.460* (0.023)	0.280 (0.013)	0.042 (0.002)
6th	c	0.110 (0.005)	1.460* (0.071)	0.500* (0.024)	0.200** (0.010)	0.050 (0.002)
	c+1	0.110 (0.005)	1.250* (0.062)	0.370* (0.017)	0.450 (0.022)	0.040 (0.002)

Potassium

In 1999, the content of K in all development stages was in current needles: 0.64–0.72% and c+1: 0.45–0.57%. These are considered optimal levels according to Stefan et al. (1997), but low levels according to Arndt et al. (1987). In 2003, the content of this element decreased significantly in all spruce stand age classes, to the values in current needles 0.50–0.65% and in c+1 0.37–0.49%. This is ranked below the optimal values (Arndt et al. 1987; Stefan et al. 1997).

Calcium

The content of Ca in 1999 in all spruce age classes was in current needles: 0.21–0.40% and in c+1: 0.31–0.59%, which are optimum levels according to Stefan et al. (1997) but low levels (especially in the 2nd, 5th and 6th age classes) according to Arndt et al. (1987) and Cape et al. (1990). After five years the content of Ca decreased significantly in the youngest age class (in current needles from 0.4 to 0.29% and in c+1 from 0.59 to 0.45%). The decrease of Ca content was also noticed with increasing stand age both in 1999 and 2003, and the differences between the oldest and the youngest age classes were statistically significant.

Magnesium

The content of Mg in 1999 in all spruce age classes was in current needles 0.054–0.064% and in c+1 0.044–0.063%. This is considered as deficient according to Stefan et al. (1997), and treated as conspicuous deficit according to Zöttl (1990). After five years the content of Mg decreased in current needles to 0.050–0.060% and in c+1 to 0.040–0.055%.

Relations between elements

The ratio S/Ca (0.6) in 1999 and 2003 indicated that only the oldest stands were still affected by high sulphur deposition. A more worrying effect was observed for the N/Ca ratio. In 1999 this ratio was within 2–5, but five years later it increased significantly to a range 3–7 in all spruce stand age classes (except for the youngest one). This indicated the effect of high nitrogen deposition (Cape et al. 1990; Małek and Astel 2008; Małek 2010). Even stronger was an increasing tendency for N/Mg: from 14–19 in 1999 to 16–31 in 2003. Especially, in the oldest spruce stand the high increase from 16 to 29 was observed (Tab. 2).

Litterfall

Higher concentrations of K and Mg in current needles in comparison with one year-old needles (Tab. 2) were noted, and they were higher also in comparison with needles in litterfall from all the age classes: 0.132–0.169% for K and 0.031–0.048% for Mg (Tab. 3). This confirmed that the age of the studied tissue has an important effect on the internal concentrations of these elements. It is known that young, current needles

Tab. 3. Average total content (in % of dry mass) of chosen elements in different fractions of the litterfall during 1999–2003 in different age classes of *Picea abies* stands in the Potok Dupniański catchment. Significant differences between the oldest and youngest age classes at p = 0.05 are indicated by * – standard errors are given in parentheses

Fraction	C	S	N	K	Ca	Mg
1st age class						
needles	44.955 (2.241)	0.069 (0.003)	0.779 (0.036)	0.132 (0.006)	0.634 (0.031)	0.048 (0.002)
shoots	45.435 (2.245)	0.075 (0.003)	0.770 (0.037)	0.089 (0.004)	0.381 (0.018)	0.029 (0.001)
others	41.994 (2.205)	0.079 (0.004)	0.914 (0.045)	0.150 (0.007)	0.472 (0.023)	0.055 (0.002)
2nd age class						
needles	45.123 (2.226)	0.087 (0.004)	0.940 (0.047)	0.161 (0.008)	0.509 (0.025)	0.045 (0.002)
shoots	47.160 (2.325)	0.063 (0.003)	0.605 (0.030)	0.056 (0.002)	0.259 (0.012)	0.019 (0.001)
others	42.157 (2.105)	0.088 (0.004)	1.008 (0.050)	0.139 (0.006)	0.315 (0.015)	0.041 (0.002)
5th age class						
needles	45.282 (2.224)	0.080 (0.004)	0.830 (0.041)	0.161 (0.008)	0.376* (0.017)	0.031* (0.001)
shoots	47.176 (2.352)	0.076 (0.003)	0.642 (0.032)	0.062 (0.003)	0.268 (0.013)	0.017 (0.001)
others	43.580 (2.152)	0.105 (0.005)	1.136 (0.055)	0.132 (0.006)	0.254 (0.012)	0.034 (0.001)
cones	47.358 (2.350)	0.055 (0.002)	0.660 (0.033)	0.441 (0.022)	0.035 (0.001)	0.045 (0.002)
6th age class						
needles	45.535 (2.225)	0.077 (0.003)	0.853 (0.042)	0.169 (0.008)	0.367* (0.018)	0.033* (0.001)
shoots	46.776 (2.356)	0.067 (0.003)	0.653 (0.032)	0.084 (0.004)	0.311 (0.015)	0.023 (0.001)
others	42.710 (2.124)	0.097 (0.004)	0.964 (0.047)	0.108 (0.005)	0.326 (0.016)	0.031 (0.001)
cones	47.150 (2.324)	0.052 (0.002)	0.582 (0.026)	0.125 (0.006)	0.087 (0.004)	0.026 (0.001)

have higher concentrations of N, K and Mg, but lower concentrations of Ca in comparison with older, one or two-years-old needles (Nihlgard 1972, 1989). Significantly lower contents of Ca and Mg were also noted in litterfall needles from the two oldest spruce stands (0.367–0.376% for Ca and 0.031–0.033% for Mg) in comparison with the younger one (0.509–0.634% for Ca and 0.045–0.048% for Mg). Thus, there was ob-

Tab. 4. Average amounts of litterfall fractions (in $kg \cdot ha^{-1} \cdot year^{-1}$), their percentage proportions and contents of elements (kg/ha) reaching the soil surface with litterfall in different age classes of *Picea abies* stands in the Potok Dupniański catchment in 1999–2003. Significant differences between the oldest and youngest age classes at p = 0.05 are indicated by * – standard errors are given in parentheses

Fraction	Mass	%	C	S	N	K	Ca	Mg
1st age class								
needles	966.9 (46.2)	64.0	428.03 (21.2)	0.66 (0.03)	6.92 (0.34)	1.16 (0.05)	6.13 (0.30)	0.44 (0.02)
shoots	135.3 (7.5)	9.0	65.10 (3.2)	0.11 (0.01)	1.03 (0.05)	0.10 (0.01)	0.41 (0.02)	0.03 (0.01)
others	407.8 (20.0)	27.0	173.27 (8.5)	0.30 (0.01)	3.46 (0.16)	0.91 (0.04)	2.17 (0.11)	0.24 (0.01)
Sum	1510.0 (70.5)	100.0	666.40 (33.2)	1.07 (0.05)	11.41 (0.50)	2.17 (0.11)	8.71 (0.42)	0.70 (0.03)
2nd age class								
needles	2779.7 (135.1)	87.5	1261.18 (62.3)	2.48 (0.07)	26.61 (1.30)	4.40 (0.21)	14.28 (0.71)	1.27 (0.05)
shoots	191.8 (8.5)	6.0	86.16 (4.2)	0.11 (0.01)	0.99 (0.04)	0.09 (0.01)	0.47 (0.02)	0.03 (0.01)
others	203.9 (10.1)	6.4	86.40 (4.3)	0.17 (0.01)	1.94 (0.09)	0.27 (0.01)	0.61 (0.03)	0.08 (0.01)
Sum	3175.4 (156.2)	100.0	1433.74 (71.2)	2.76 (0.13)	29.53 (1.45)	4.76 (0.23)	15.36 (0.75)	1.38 (0.06)
5th age class								
needles	2516.5 (125.1)	47.8	1137.58 (50.5)	1.97 (0.09)	20.54 (1.00)	3.52 (0.14)	9.30 (0.46)	0.75 (0.03)
shoots	431.3 (21.4)	8.2	200.01 (9.8)	0.30 (0.01)	2.64 (0.13)	0.25 (0.01)	1.16 (0.05)	0.07 (0.01)
others	364.5 (17.1)	6.9	158.76 (7.4)	0.35 (0.01)	3.80 (0.16)	0.51 (0.02)	0.94 (0.04)	0.13 (0.01)
cones	1953.7 (94.5)	37.1	916.41 (45.2)	0.85 (0.04)	8.69 (0.43)	5.41 (0.26)	0.64 (0.03)	0.58 (0.02)
Sum	5266.1* (261.2)	100.0	2412.77* (120.5)	3.47* (0.17)	35.67* (1.72)	9.69* (0.46)	12.04* (0.60)	1.53* (0.07)
6th age class								
needles	2526.0 (124.2)	34.9	1152.59 (50.6)	1.92 (0.09)	21.36 (1.05)	3.70 (0.13)	9.41 (0.45)	0.79 (0.03)
shoots	383.0 (19.0)	5.3	172.71 (8.4)	0.23 (0.01)	2.26 (0.11)	0.38 (0.02)	1.14 (0.05)	0.10 (0.01)
others	381.5 (18.5)	5.3	163.47 (8.1)	0.37 (0.01)	3.48 (0.16)	0.43 (0.02)	1.27 (0.06)	0.12 (0.01)
cones	3943.6 (181.2)	54.5	1955.60 (96.2)	1.91 (0.08)	19.41 (0.82)	8.48 (0.41)	2.12 (0.10)	0.99 (0.04)
Sum	7234.1* (361.2)	100.0	3444.37* (171.2)	4.43* (0.21)	46.50* (2.30)	12.99* (0.64)	13.95* (0.65)	1.99* (0.08)

served a decrease of the content of these elements with age of the spruce stands (Tab. 3).

The results of the litterfall analyses (Tab. 4) indicated that with the increasing forest age the amount of litterfall showed the increasing tendency. This was especially due to the high amount of cones in two oldest spruce stands, and a statistically significant difference between the oldest and youngest age classes was noted. Cone participation in the litterfall mass was 55 per cent for a mature stand, and 37 per cent for a maturating stand. Thus, the importance of cones in the mass of litterfall was evident in old stands. The largest quantity of needles per hectare occurred in the 2nd (2780 $kg \cdot ha^{-1} \cdot year^{1}$) and in the 6th age classes (around 2500 $kg \cdot ha^{-1} \cdot year^{1}$). Twigs made a relatively small quantity, the maximum portion was around 6% of the total litterfall. In the absolute values their largest quantities occurred in the 5th age class (ca 430 $kg \cdot ha^{-1} \cdot year^{1}$), while the smallest amounts appeared in the 1st age class – 135 $kg \cdot ha^{-1} \cdot year^{1}$.

Discussion

Nitrogen is normally the nutrient most limiting forest growth in boreal forest ecosystems (Tamm 1991), but when more N is available through deposition, the growth increases and other nutrients may become growth-limiting. Together with nutrient loss caused by leaching of for example K, Ca, and Mg followed by soil acidification (Falkengren-Grerup et al. 1987), an increased demand for mineral nutrients may result in nutrient deficiencies in trees. Deficiencies related to nitrogen deposition were shown for Mg and K (Hűttl 1990), Ca and Mg (Katzensteiner et al. 1992) as well as for basic cations and micronutrients (Thelin et al. 1998).

The low content of Mg in spruce needles is tightly connected with the relatively small content of Mg (Nihlgård 1972; Małek 2004, 2010). A deficiency of Mg is considered a key cause of Norway spruce yellowing damage typical for this part of Europe (de Vries et al. 2007). Discoloration above 20% was observed in this study, especially in the two oldest spruce stands. (Tab. 1). The sudden incidence of this symptom may be attributed to a series of dry years, which reduced Mg mineralization and uptake, as well as by more intensive tree harvesting (shorter rotation) and leaching of soils by acid rain (Adams et al. 2000). An increase of Mg deficit might thus be caused by water stress, as during dry years Mg is mineralized from litter to a lower extent, followed by a decreased uptake from soil and poorer development of the root systems. Finally, due to higher nitrification the leaching of nitrates in combination with Mg can be more intensive with coming rainfall. As demonstrated by studies conducted in spruce stands in Mid-German uplands (Roberts et al. 1989) the deficiency of Mg in needles may be caused by a reduced level of Mg in soil, resulting from wood harvesting and leaching by acid rain, rather than by direct washing of Mg from needles in connection with air pollution (Małek 2004, 2010; Małek and Astel 2008). The obtained results of element concentrations in the needles of litterfall also demonstrated that before the needles were shed some translocation of N and K occurred, and especially of Mg, which deficient both in the assimilation organ and soil (Małek 2004, 2010; Małek et al. 2005).

The amounts of litterfall in the Dupniański Stream catchment (Tab. 4) were within the limits given by different authors (from 1 000 to 7 000 $kg \cdot ha^{-1} \cdot year^{1}$). In the study of Novák and Slodičák (2000) carried out in 1992–1996 (in the Orlickie Mts.), in 31 years old spruce stands (reminiscent of 2nd age class on the Potok Dupniański catchment) the total litterfall mass was about 3 500 $kg \cdot ha^{-1} \cdot year^{1}$ which was lower than that observed in the Silesian Beskid. Carey and Farrell (1978) pointed out that 34–47 years old spruce stands delivered around 5 500 $kg \cdot ha^{-1} \cdot year^{1}$ of litterfall. Nihlgård (1972, 1989) reported 5 600 $kg \cdot ha^{-1} \cdot year^{1}$in 55 years old spruce stands. Such litterfall amounts were also observed in the Potok Dupniański catchment in the 5th age spruce stand class (Tab. 4). In 80 years old stands (Dietrich, cit. Schmidt-Vogt 1986) growing in bleached brown soils the litterfall was 3 tons. Its composition included 68–86 per cent of needles and 10–26 per cent of animal debris and excrements. It seemed that the culmination time for needle shedding came at the moment of most acute competition between trees, and the strongest process of cleanup of tree trunks. The smallest amount of shed needles observed in thickets was probably a result of small sizes of tree crowns.

In comparison with rainfall supply (Małek 2004, 2010, Małek and Astel 2008), the litterfall (Tab. 4) supplied considerable amounts of N, K, Ca and Mg to the forest floor. However, in acid and frequently dried out or

flooded soils where fungi and saprophytes (Collembola) dominate, decomposition of spruce litter may be markedly reduced, followed by formation of moder and raw humus.. As a consequence, the habitat becomes even more impoverished, and so does the content of nutrients in needles while the process of degradation moves on (Fiedler 1979). In order to improve spruce stability we have to increase the retention and availability of basic cations, and one way to do this could be through conversion of tree species in forest stands.

Conclusions

– The content of S was at its optimum value only in the oldest spruce stand in 1999 and 2003, whereas the content of N in 1999 in all spruce stand development stages was low and below optimum values. After five years, the content of N significantly increased in all stand age classes, especially in the oldest, and the averages reached normal and optimum levels except in the 1st age class. Significant increases of the total content of N between 1999 and 2003 was noted for all spruce stands, except for the youngest one.
– In 1999 the content of K in all development stages was at optimum levels. In 2003, the contents of this element decreased significantly in all spruce stand age classes, and were below the optimum values, The content of Mg was evaluated as deficient in 1999 in all spruce age classes, and after five years it decreased even more, which resulted in discoloration of the tree crowns.
– The content of Ca in 1999 was at low levels especially in the 2nd, 5th and 6th age classes. After five years, the content of Ca decreased significantly in the youngest age class. The decrease of Ca was also observed with increased age of studied spruce stands both in 1999 and 2003, and the differences between the oldest and the youngest age classes were statistically significant.
– Both in 1999 and 2003, the S/Ca ratio indicated that the oldest stands were still affected by high sulphur deposition. The N/Ca ratio was low in 1999, but after five years it increased in all spruce stand age classes, except in the youngest one. Even stronger was the tendency of increase of the N/Mg ratio from 1999 to 2003. This was especially true for the oldest spruce stands, indicating the effect of high nitrogen deposition which could affect spruce tree vitality and health.
– Low content of Mg in spruce needles is tightly connected with relatively small amounts of Mg easily uptaken by trees from soil. The leaching of Mg out the rhizosphere was considered as the key cause of Norway spruce discoloration, especially in the two oldest stands in 1999, which significantly increased in all spruce stands age classes in 2003.

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